



TITLE:

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A common stabilization of diagrams of a knot

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An oriented *knot* is an oriented circle smoothly embedded in the space \mathbb{R}^3 . We consider oriented knots up to ambient isotopy in \mathbb{R}^3 . We do not distinguish a knot and its ambient isotopy class so long as no confusion occurs. Let $\pi : \mathbb{R}^3 \rightarrow \mathbb{R}^2$ be a natural projection defined by $\pi(x, y, z) = (x, y)$. Let K be an oriented knot in \mathbb{R}^3 . Suppose that the multiple points of the restriction of π to K are only finitely many transverse double points. Then the image $\pi(K)$ together with over/under information at each double point is called a *knot diagram* of K . A double point of a knot diagram is called a *crossing point*. We do not distinguish a knot diagram and its ambient isotopy class in \mathbb{R}^2 so long as no confusion occurs.

The *Reidemeister moves* are local moves on knot diagram illustrated in Figure 1. Let n be a positive integer. A sequence of knot diagrams D_1, \dots, D_n on \mathbb{R}^2 is said to be a *Reidemeister sequence* if D_{i+1} is obtained from D_i by an application of one of the Reidemeister moves for each i with $1 \leq i \leq n-1$. It is well-known that two knot diagrams of the same knot are transformed into each other by a finite number of applications of Reidemeister moves. Namely for any two diagrams D and E of a knot K there is a Reidemeister sequence D_1, \dots, D_n with $D = D_1$ and $D_n = E$. Then we say that D_1, \dots, D_n is a Reidemeister sequence from D to E . We denote the number of crossings of a knot diagram D by $c(D)$.

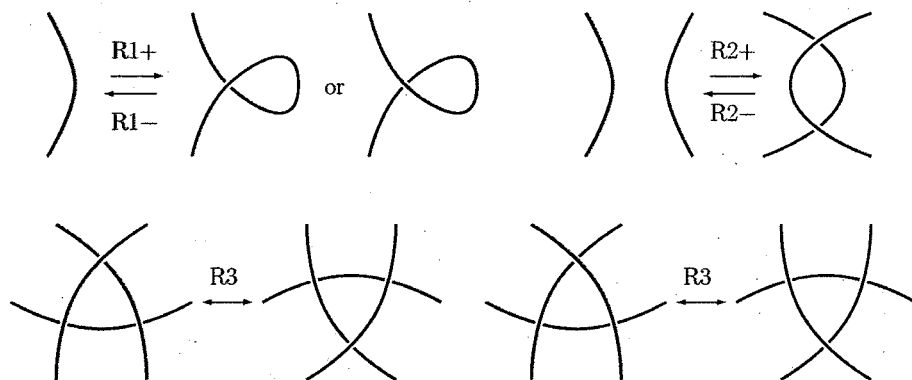


FIGURE 1. Reidemeister moves

It is also well-known that there are a knot K and two diagrams D and E of K such that for any Reidemeister sequence D_1, \dots, D_n from D to E , there exists $i \in \{2, \dots, n-1\}$ such that $c(D_i) > \max\{c(D), c(E)\}$. For example, let K_0 be a knot that bounds a disk in \mathbb{R}^3 , D Goeritz's unknot illustrated in Figure 2 and E a unit circle on the plane. Goeritz's unknot is a knot diagram of K_0 [2]. Note that it has no loops and triangles, and each 2-gon of it has alternating crossings. Therefore

we can only apply R1+ or R2+ to it among other Reidemeister moves. Therefore if D_1, \dots, D_n is a Reidemeister sequence from D to E , then $c(D_2) = c(D_1) + 1$ or $c(D_2) = c(D_1) + 2$ and therefore $c(D_2) > c(D_1) = c(D) = \max\{c(D), c(E)\}$.

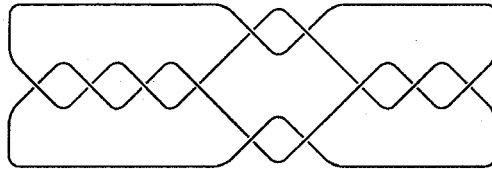


FIGURE 2. Goeritz's unknot

However it is known that there is a function $f(x)$ such that for any diagram D of the knot K_0 , there exists a Reidemeister sequence D_1, \dots, D_n from D to a unit circle E with $\max\{c(D_i) | i \in \{1, \dots, n\}\} \leq f(c(D))$. See [3] and [4].

A knot diagram E is said to be a *stabilization* (resp. *strong stabilization*) of a knot diagram D if there exists a Reidemeister sequence D_1, \dots, D_n with $n \geq 1$ from D to E such that $c(D_1) \leq \dots \leq c(D_n)$ (resp. $c(D_1) < \dots < c(D_n)$). By definition D is a strong stabilization of D itself. Note that Goeritz's unknot is not a stabilization of a unit circle. Let D_1, \dots, D_m be knot diagrams. A knot diagram D is said to be a *common stabilization* (resp. *common strong stabilization*) of D_1, \dots, D_m if D is a stabilization (resp. strong stabilization) of D_i for each $i \in \{1, \dots, m\}$.

Theorem 1. (Alexander Coward 2006 [1]) *Let K be a knot and D and E diagrams of K . Then there is a Reidemeister sequence from D to E such that the sequence is composed of a sequence of applications of R1+, followed by a sequence of applications of R2+, followed by a sequence of applications of R3, followed by a sequence of applications of R2-.*

Corollary 2. *Let K be a knot and D and E diagrams of K . Then there exists a diagram F of K such that F is a stabilization of D and F is a strong stabilization of E .*

Corollary 3. *Let K be a knot and D_1, \dots, D_m diagrams of K . Then there exists a diagram D of K such that D is a common stabilization of D_1, \dots, D_m .*

Example 4. Let D and E be knot diagrams illustrated in Figure 3. Note that D is a diagram of the knot $3_1 \# 3_1 \# 3_1^* \# 3_1^*$ and E is a diagram of the knot $3_1 \# 3_1^* \# 3_1 \# 3_1^*$ where 3_1 denotes the right-handed trefoil knot, 3_1^* denotes the left-handed trefoil knot and $J \# K$ denotes the connected sum of two knots J and K . Since connected sum operation is commutative we have $3_1 \# 3_1 \# 3_1^* \# 3_1^* = 3_1 \# 3_1^* \# 3_1 \# 3_1^*$. Therefore D and E are diagrams of the same knot. By pulling one of 3_1^* tight and sliding it along one of 3_1 we have a Reidemeister sequence from D to E through diagrams at most 14 crossings. However the corresponding sequence of crossing numbers cannot be divided into a weakly increasing sequence and a subsequent weakly decreasing sequence. Let F be a knot diagram illustrated in Figure 3. Note that E is obtained from F by 12 times applications of R2- and D is obtained from F by 54 times

applications of R3 followed by 12 times applications of R2-. Therefore F is a strong stabilization of E and F is a stabilization of D .

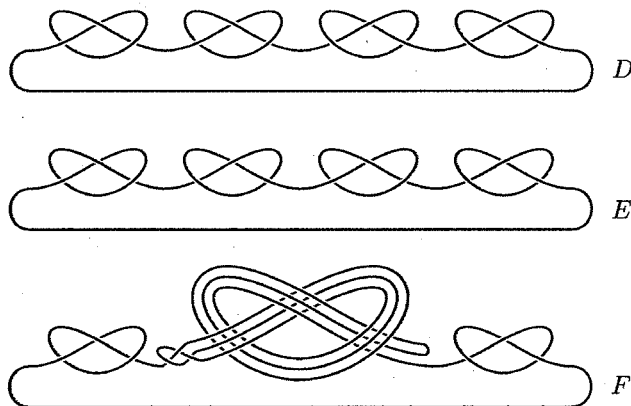


FIGURE 3. F is a common stabilization of D and E

We note that Corollary 2 is best possible. Namely we have the following results. A knot diagram D is said to be (R1, R2)-*reduced* if D has no loops and each 2-gon of D has alternating crossings. Then the following theorem is a paraphrase of a result in [8, Theorem 3.2] where not only knot diagrams but also link diagrams are considered. We note that a closely related result is shown in [5, Theorem 2.2 (3)]. See also [6] and [7].

Theorem 5. *Let K be a knot and D and E (R1, R2)-reduced diagrams of K . Suppose that D and E have a common strong stabilization. Then D and E are ambient isotopic on \mathbb{R}^2 as oriented knot diagrams, or both D and E are simple closed curves with opposite orientations.*

Corollary 6. *For any knot K , there are diagrams D and E of K that have no common strong stabilizations.*

Proof. It is clear that K has at least one (R1, R2)-reduced diagram D . Let E be a diagram-connected sum of D and a Goeritz's unknot. Then E is also a (R1, R2)-reduced diagram of K . Since D and E are not ambient isotopic on \mathbb{R}^2 , Theorem 5 implies that they have no common strong stabilizations. \square

Two knot diagrams D and E are said to be R1-R2-*equivalent* if there exists a Reidemeister sequence D_1, \dots, D_n with $D = D_1$ and $D_n = E$ such that D_{i+1} is obtained from D_i by an application of one of R1+, R1-, R2+ and R2- for each i with $1 \leq i \leq n - 1$. The following is an immediate consequence of Theorem 5.

Theorem 7. *Let K be a knot and D and E diagrams of K . Let D' and E' be (R1, R2)-reduced diagrams obtained from D and E respectively by applications of R1- and R2-. Then the following conditions are equivalent.*

- (1) *Two diagrams D and E are R1-R2-equivalent.*

- (2) Two diagrams D' and E' are ambient isotopic on \mathbb{R}^2 as oriented knot diagrams, or both D' and E' are simple closed curves with opposite orientations.

Proof. Suppose that D' and E' are ambient isotopic on \mathbb{R}^2 as oriented knot diagrams. Then D and E are R1-R2-equivalent. Suppose that both D' and E' are simple closed curves with opposite orientations. It is easy to see that D' and E' are R1-R2-equivalent. Therefore D and E are R1-R2-equivalent. Thus we have shown that the condition (2) implies the condition (1).

Suppose that D and E are R1-R2-equivalent. Let D_1, \dots, D_n be a Reidemeister sequence with $D = D_1$ and $D_n = E$ such that D_{i+1} is obtained from D_i by an application of one of R1+, R1-, R2+ and R2- for each i with $1 \leq i \leq n-1$. Let D'_i be an (R1, R2)-reduced diagram obtained from D_i by applications of R1- and R2- for each i with $2 \leq i \leq n-1$. Let $D'_1 = D'$ and $D'_n = E'$. Then D_i or D_{i+1} is a common strong stabilization of D'_i and D'_{i+1} for each i with $1 \leq i \leq n-1$. Then by Theorem 5 D'_i and D'_{i+1} are ambient isotopic on \mathbb{R}^2 as oriented knot diagrams, or both D'_i and D'_{i+1} are simple closed curves with opposite orientations for each i with $1 \leq i \leq n-1$. Therefore $D' = D'_1$ and $E' = D'_n$ are ambient isotopic on \mathbb{R}^2 as oriented knot diagrams, or both D' and E' are simple closed curves with opposite orientations. Thus we have shown that the condition (1) implies the condition (2).

□

REFERENCES

- [1] A. Coward, Ordering the Reidemeister moves of a classical knot, *Algebr. Geom. Topol.*, **6** (2006), 659-671.
- [2] L. Goeritz, Bemerkungen zur knotentheorie, *Abh. Math. Sem. Univ. Hamburg*, **10** (1934), 201-210.
- [3] J. Hass and J. Lagarias, The number of Reidemeister moves needed for unknotting, *J. Amer. Math. Soc.*, **14** (2001), 399-428.
- [4] A. Henrich and L. Kauffman, Unknotting unknots, *Amer. Math. Monthly*, **121** (2014), 379-390.
- [5] N. Ito and Y. Takimura, (1,2) and weak (1,3) homotopies on knot projections, *J. Knot Theory Ramifications*, **22** (2013), No. 14, 1350085, 14 pp.
- [6] N. Ito and Y. Takimura, Addendum: (1,2) and weak (1,3) homotopies on knot projections, *J. Knot Theory Ramifications*, **23** (2014), No. 8, 1491001, 2 pp.
- [7] M. Khovanov, Doodle groups, *Trans. Amer. Math. Soc.*, **349** (1997), 2297-2315.
- [8] K. Sasaki, On link diagrams that are minimal with respect to Reidemeister moves I and II, arXiv:1612.00764.

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